Available online at www.sciencedirect.com
ScienceDirect
Agriculture, Ecosystems and Environment 119 (2007) 135–144
Agriculture Ecosystems & Environment
www.elsevier.com/locate/agee

Energy use efficiency of specialised dairy, arable and pig farms in Flanders

Marijke Meul [a,*], Frank Nevens [a], Dirk Reheul [b], Georges Hofman [c]

[a] Flemish Policy Research Centre for Sustainable Agriculture, Potaardestraat 20, B-9090 Gontrode, Belgium
[b] Department of Plant Production, Ghent University, Coupure Links 653, B-9000 Gent, Belgium
[c] Department of Soil Management and Soil Care, Ghent University, Coupure Links 653, B-9000 Gent, Belgium

Received 3 February 2006; received in revised form 27 June 2006; accepted 3 July 2006
Available online 7 September 2006

Abstract

In this study, we determined the energy use and energy use efficiency of a representative set (Flemish Farm Accountancy Data Network, FADN) of specialised dairy, arable and pig farms in Flanders. Total energy use comprised direct energy, based on the consumed amounts of diesel, lubricants, electricity and other energy sources (p.e. natural gas); and indirect energy, consumed during the production of farm inputs such as mineral fertilisers, seeds, pesticides, concentrates, forages and field machinery. We studied the changes in energy use and energy use efficiency between 1989–1990 and 2000–2001 for dairy and arable farms and between 1989–1990 and 1997–1998 for pig farms. The results showed that the use of mineral fertilisers and animal feed accounted for a high share of the total energy use on the farms. Diesel use took the major part of direct energy use. For dairy and arable farms, total energy use per ha has decreased significantly over the considered time period; on pig farms, energy use per fattening pig equivalent (FPE) in 1997–1998 was comparable to that in 1989–1990. The most energy efficient dairy and pig farms were intensive farms, which combined a high production with a low energy use and which possessed a gross value added per production unit comparable to, or even higher than the average. Based on the energy productivity of the top 5% farms, target values were set of 35 l milk 100 MJ^{-1} and 7.5 kg carcass 100 MJ^{-1} for energy use on Flemish dairy and pig fattening farms, respectively. On arable farms, the energy use efficiency was highly dependent on the crop rotation. For that reason, it is recommended to calculate energy balances on field level, for each separate crop.

Keywords: Arable farming; Dairy farming; Energy use efficiency; Flanders; Pig farming

1. Introduction

Efficient use of resources is one of the major assets of eco-efficient and sustainable production, also in agriculture. Eco-efficiency is a management approach that was acknowledged at the 1992 Rio Earth Summit as a way for companies and businesses to contribute to sustainable development (de Jonge, 2004). Eco-efficient production has been given many definitions, all of them however adding up to the one principle ‘produce more from less’; adding maximum value with minimum use of resources and with minimum environmental impact (WBCSD, 2000; Jollands et al., 2004). In this study we focus on one aspect of eco-efficiency in agricultural production systems: energy use efficiency.

Inefficient energy use can result in severe environmental impacts. The emission of greenhouse gasses by combustion of fossil fuels contributes to climate change. As a consequence, the global mean temperature has increased during the past 100 years and raised concerns over global warming and uncertainty over future impacts on the climate (a.o. Pimentel et al., 1996). The reduction of greenhouse gas emissions requires a decreased use of fossil fuels. Partly this can be achieved by using more sustainable sources of ‘green energy’, such as wind, bio energy and solar energy; or by a substantial increase of the energy use efficiency (Corré et al., 2003), where the same amount of output is produced with

* Corresponding author. Tel.: +32 9 264 90 75; fax: +32 9 264 90 94.
E-mail address: Marijke.Meul@UGent.be (M. Meul).

0167-8809/$ – see front matter
doi:10.1016/j.agee.2006.07.002

less energy. The development of energy efficient agricultural systems – with a low input of energy compared to the output of products – should therefore help to reduce agricultural emissions of greenhouse gasses (Dalgaard et al., 2001). To achieve this, knowledge about energy use in different agricultural systems is needed.

On farms, energy – whether fossil or renewable – is consumed in a 'direct' and an 'indirect' way (Hülsbergen et al., 2001; Pervanchon et al., 2002; Corré et al., 2003). Direct energy is used on farm for agricultural activities, the use is directly measurable and it comprises mainly diesel fuel, electricity and natural gas. The energy that is used to produce farm inputs such as mineral fertilisers, seeds, pesticides, concentrates, forages and machines is indirect energy.

Energy use efficiency is often expressed by the 'energy price' (EP) of agricultural products (a.o. Refsgaard et al., 1998; Corré et al., 2003). This is the amount of energy (in MJ) needed for the production of one unit of product (e.g. 1 kg wheat, 1 l milk). The energy use involves all energy used directly and indirectly up to the moment that the products leave the farm ('farm gate approach'). In our study, we prefer to express energy use efficiency as the reverse of the EP (i.e. the amount of product produced with one unit of energy), since this better fits the above definition of eco-efficiency: produce more (output) from less (input).

In this paper we study energy use efficiency, comparing energy input to production output, of three major agricultural systems in Flanders. Our major aims are:

- to determine the total (direct + indirect) energy use of a representative set of specialised dairy, arable and pig farms in Flanders and calculate their energy use efficiencies;
- to study the changes in energy use and energy use efficiency on farm level between 1989 and 2001;
- to set achievable targets for energy use efficiency on farms in Flanders.

2. Materials and methods

2.1. Data and farm characteristics

The Flemish Farm Accountancy Data Network (FADN) is a database of technical and economic data from a representative set of Flemish farms. From this dataset we used the data of the specialised dairy and arable farms in 1989, 1990, 2000 and 2001. For the specialised pig farms, we used the data of 1989, 1990, 1997 and 1998; data of 2000 and 2001 were considered unreliable, due to a food safety hazard in the sector in Flanders (dioxin in the production chain).

We considered dairy farms as 'specialised' when at least 95% of the farm income originated from dairy activity. On specialised arable farms and specialised pig farms, at least 66% of the standard gross margin (SGM) originated from arable or pig production, respectively; SGM being the average monetary value of gross production minus specific costs for a given region (Commission of the European Communities, 1985).

A selection of average characteristics of the farms is presented in Table 1.

2.2. System boundaries

Jones (1989) presented a hierarchy of methods for energy use analysis in agro-ecosystems, based on the applied system boundaries. The method used in our study corresponds to 'process analysis', where all energy inputs (direct and indirect) to an agricultural system are considered, based on physical material flows. Human labour and solar energy are not considered in this method. We only included the indirect energy use one step backwards from the farm. This means that we included e.g. the energy used to produce fertilisers, but not the energy used to manufacture the equipment to produce the fertilisers. According to Refsgaard et al. (1998), by applying these boundaries, over 90% of the

Table 1
Average characteristics of the specialised dairy, arable and pig farms in the dataset extracted from the Flemish Farm Accountancy Data Network

	Unit	1989	1990	2000	2001
Dairy farms	#	169	165	78	69
Utilised area	ha	28	28	32	32
Stocking rate	cows ha^{-1}	1.73	1.73	1.64	1.62
Milk production	l cow^{-1} $year^{-1}$	5319	5365	6017	5827
	l ha^{-1} $year^{-1}$	9607	9567	10043	9643
Arable farms	#	64	57	55	50
Cultivated area[a]	ha	50	52	63	65
No. of crops		7	7	7	7

	Unit	1989	1990	1997	1998
Pig farms	#	85	98	97	98
No. of pigs	FPE[b]	675	792	1207	1249

[a] The cultivated area is the sum of the areas of all cultivated crops during 1 year. Since a parcel of land can be used to grow more than one crop during 1 year, this area can be larger than the utilised area.

[b] FPE = fattening pig equivalent: 1 fattening pig = 1 young sow = 1 FPE; 1 sow = 2 FPE; 1 boar = 1.5 FPE.

energy input in the whole production process of farm inputs is covered. We considered the energy used up to the point where the products leave the farm ('farm gate approach', Corré et al., 2003), which means that the energy required for packing, drying, storing and transporting products from the farm to consumers was not taken into account.

Our system limits are supported by the fact that our major aim is to evaluate farm energy use, not to make a complete life cycle analysis of a product.

2.3. Energy input parameters

For each year considered, we calculated the total of direct and indirect energy input (MJ) of a farm. Thereby, we considered direct energy input as the energy used on the farm for field and livestock operations, comprising diesel fuel (including contract work diesel), lubricants, electricity and other energy carriers (e.g. natural gas). The accounted energy included the caloric energy content (this is the

Table 2
FADN entries and energetic values used to calculate the different production inputs

Input	FADN entries		Energetic values		
	Data	Unit	Value	Unit	Reference[a]
Direct energy					
Diesel	Amount of diesel	l	40.68	$MJ\ l^{-1}$	Dalgaard et al. (2001), Wells (2001), Hülsbergen et al. (2001), Maertens and Van Lierde (2003), Vito (2004), Australian Institute of Energy (2004), Boustead (2003)
Lubricants	Amount of diesel	l	3.6	$MJ\ l^{-1}$ diesel[b]	Dalgaard et al. (2001)
Electricity	Amount of electricity	kWh	5.65[c]	$MJ\ kWh^{-1}$	Maertens and Van Lierde (2003), Vito (2004), EMA (2002), FPS Economy, SMEs, Self-employed and Energy (2004)
Other sources[d]	Amount of energy	MJ			
Indirect energy					
Field crops					
Seeds[e]					
Winter wheat	Cultivated area	ha	571	$MJ\ ha^{-1}$	Hülsbergen et al. (2001), Refsgaard et al. (1998), Dekkers (2002)
Sugar beet	Cultivated area	ha	419	$MJ\ ha^{-1}$	Hülsbergen et al. (2001), Ministry of Agriculture (2001), Bonnez (2006)
Potato	Cultivated area	ha	1300	$MJ\ ha^{-1}$	Hülsbergen et al. (2001), PCA (2006)
Maize	Cultivated area	ha	168	$MJ\ ha^{-1}$	Wells (2001), Dekkers (2002)
Grass	Cultivated area	ha	132	$MJ\ ha^{-1}$	Wells (2001), Dekkers (2002)
Mineral fertilizer					
N	Amount of N	kg	55.3	$MJ\ kg^{-1}$	Dalgaard et al. (2001), Wells (2001), Hülsbergen et al. (2001), Gezer et al. (2003), Gliessman (2000)
P_2O_5	Amount of P_2O_5	kg	15.8	$MJ\ kg^{-1}$	Hülsbergen et al. (2001)
K_2O	Amount of K_2O	kg	9.3	$MJ\ kg^{-1}$	Hülsbergen et al. (2001)
Pesticides					
Fungicides	Amount of active ingredient	kg	276	$MJ\ kg^{-1}$ AI[f]	Dalgaard et al. (2001), Wells (2001), Hülsbergen et al. (2001)
Herbicides	Amount of active ingredient	kg	214	$MJ\ kg^{-1}$ AI	Dalgaard et al. (2001), Hülsbergen et al. (2001), Gezer et al. (2003)
Insecticides	Amount of active ingredient	kg	278	$MJ\ kg^{-1}$ AI	Dalgaard et al. (2001), Hülsbergen et al. (2001)
Field machinery	Amount of diesel	l	12	$MJ\ l^{-1}$ diesel[b]	Dalgaard et al. (2001)
Animal production					
Dairy cows					
Concentrates	Amount of purchased concentrates	kg	6.3	$MJ\ kg^{-1}$	de Haan and Feikema (2001)
Maize silage	Amount of purchased forage	kg	2.2	$MJ\ kg^{-1}$ DM[g]	Wells (2001), de Haan and Feikema (2001)
Grass silage	Amount of purchased forage	kg	1.5	$MJ\ kg^{-1}$ DM	Wells (2001)
Pig production					
Piglets feed	Amount of purchased feed	kg	6	$MJ\ kg^{-1}$	van der Werf et al. (2005)
Pig feed	Amount of purchased feed	kg	3.4	$MJ\ kg^{-1}$	van der Werf et al. (2005)
Sow feed	Amount of purchased feed	kg	3.7	$MJ\ kg^{-1}$	van der Werf et al. (2005)

[a] In case of multiple references, average values were used.
[b] The energy input from lubricants and the energy needed for production of field machinery is related to the amount of diesel used during field operations.
[c] This value takes into account the share of electricity from nuclear energy and fossil fuels. All necessary data were found in the cited references.
[d] Other sources: direct energy use from energy carriers other than diesel and electricity; not further specified in FADN.
[e] We accounted the energy required to produce the amount of seed necessary for the production of 1 ha of the crop.
[f] Active ingredient.
[g] Dry matter.

amount of energy released when the fuel is combusted) and the energy used for mining, transformation and transport of the energy carrier.

According to our above defined system boundary, indirect energy input to the farm included the energy needed for the production of mineral fertilisers, seeds, pesticides, concentrates, forages and field machinery. For indirect energy inputs, the accounted energy included the energy for their manufacturing, processing and transporting.

Total direct and indirect energy inputs on a farm were calculated on an annual base. We multiplied the consumed amounts of inputs – extracted from the FADN – by their corresponding energetic values. All energetic values used in our study were based on scientific literature, they are summarized together with the data entries from the FADN in Table 2.

2.4. Output parameters

We used the total annual milk production as the output parameter for the specialised dairy farms. We did not consider the amount of produced meat as an output parameter; firstly because the main purpose of a dairy farm is to produce milk and secondly because meat production on the studied specialised dairy farms is small (since 95% of the farm income originates from dairy activities). Therefore, we allocated the energy input only to milk production.

For the pig farms we distinguished between specialisation in piglet production (sow herds) and fattening pig production (fattening herds). For the sow herds, the total annual weight of produced piglets was used as the output parameter, while for the fattening herds, we used the total annual weight of produced carcasses. Those output parameters could be extracted directly from the FADN.

For arable farms, we calculated the total amount of produced energy, by multiplying the crop yields (extracted from FADN) with the respective energy content of the crops (Table 3). We used crop energy output instead of produced crop amounts, since this enables us to account for the various crops in a common unit.

2.5. Energy use efficiency

We expressed the energy use efficiency by the amount of product produced with one unit of energy, according to the definition of eco-efficiency: produce more (output) from less (input). For dairy farms and pig farms we therefore calculated the ratio between the amount of product (litre milk, kilogram carcass) and the total energy input, which we define as 'energy productivity'. For arable farms we calculated the ratio of total energy output and total energy input – 'energy balance' – which expresses the total amount of crop energy that is produced per unit of energy input. All calculations were made on farm level and on an annual basis.

We studied the changes in energy use efficiency between 1989 and 2001 on dairy and arable farms. For the FADN pig farms, energy productivity was only calculated for 1997–1998, since production results of 1989–1990 were not available.

Table 3
Energy contents of the most important arable crops in Flanders

Crop[a]	Energy content ($MJ\ kg^{-1}$ fresh product)	Reference[b]
Winter wheat	15.5	NOVEM (1992), Hülsbergen et al. (2001), USDA (2004), Moerschner and Lücke (2002)
Winter rye	14.0	USDA (2004)
Winter barley	15.8	Hülsbergen et al. (2001), USDA (2004), Moerschner and Lücke (2002)
Oat	16.3	USDA (2004), Moerschner and Lücke (2002)
Maize (grain)	15.3	USDA (2004)
Maize (silage)	5.5	NOVEM (1992)
Sugar beet	5.3	NOVEM (1992), Hülsbergen et al. (2001)
Potato	3.4	Hülsbergen et al. (2001), USDA (2004)
Crop seeds	16.4	Moerschner and Lücke (2002)
Vegetables	1.3	USDA (2004)
Fruits	2.0	USDA (2004)

[a] For cereals, only the grain is considered; sugar beet and potato: without leaves.
[b] In case of multiple references, average values were used.

2.6. Target values

For each farm type, we compared the average farm and management characteristics of the 5% most energy efficient farms from our dataset with those of all farms. We further used the energy use efficiency performances of those top performing 5% farms to establish achievable targets for energy use on farms in Flanders.

3. Results and discussion

3.1. Energy input

Table 4 shows the average energy inputs on the specialised dairy, arable and pig farms from our dataset. These results illustrate the importance of indirect energy input: it comprised about 70% of the total energy use on dairy and pig farms; on arable farms this was little more than 50%. Particularly the use of mineral fertilisers and animal feed accounted for a high share of the total farm energy use. On dairy farms, nearly 60% of total energy input in 2000–2001 could be attributed to the used mineral fertilisers and concentrates. On arable farms, the production of mineral fertilisers consumed 34% of total energy input and the production of pig feed accounted for 68% of total energy use on pig farms. Diesel use took the major part of direct energy

Table 4
Annual average energy input on specialised dairy, arable and pig farms in Flanders

	Dairy farms				Arable farms				Pig farms			
	1989–1990		2000–2001		1989–1990		2000–2001		1989–1990		1997–1998	
	MJ ha^{-1}	%	MJ ha^{-1}	%	MJ ha^{-1}	%	MJ ha^{-1}	%	MJ FPE^{-1} [a]	%	MJ FPE^{-1}	%
Direct energy input												
Diesel	7422	16.5	8044	22.1	7983	35.2	7899	37.7	709	19.9	810	22.8
Lubricants	524	1.2	534	1.5	571	2.5	508	2.4	5	0.1	7	0.2
Electricity	4345	9.6	3458	9.5	1063	4.7	1091	5.2	227	6.4	198	5.6
Other sources	149	0.3	109	0.3	341	1.5	519	2.5	36	1.0	25	0.7
Total	12439	27.6	12144	33.4	9958	43.9	10017	47.8	977	27.4	1040	29.2
Indirect energy input												
Mineral fertiliser	14549	32.3	8364	23.0	9171	40.4	7109	33.9	63	1.8	51	1.4
Seeds	165	0.4	163	0.4	477	2.1	470	2.2	5	0.1	5	0.1
Pesticides	189	0.4	220	0.6	1047	4.6	1490	7.1	7	0.2	8	0.2
Machinery	2228	4.9	2424	6.7	2030	8.9	1873	8.9	24	0.7	23	0.7
Cow feed												
Concentrates	15182	33.7	12897	35.5								
Forages	302	0.7	161	0.4								
Pig feed									2492	69.9	2430	68.3
Total	32616	72.4	24228	66.6	12724	56.1	10942	52.2	2590	72.6	2517	70.8
Total energy input	45055	100	36372	100	22683	100	20959	100	3567	100	3557	100

[a] Fattening pig equivalent.

use and accounted for about 23% of total energy use on dairy and pig farms, and for 38% of total energy use on arable farms.

For dairy and arable farms, total energy use per ha has decreased significantly over the considered time period (−19% on dairy farms and −8% on arable farms). This decrease mainly originated from a lower use of mineral fertilisers and concentrates (Table 4). On pig farms, the energy use per fattening pig equivalent (FPE) in 1997–1998 was comparable to that in 1989–1990.

3.2. Energy use efficiency

3.2.1. Dairy farms

Fig. 1 shows the total energy input per ha in relation to the production intensity (litre milk per hectare) of dairy farms. In 1989–1990, 90% of the set of specialised dairy farms operated between energy productivity isoquants of 14.5 and 30.0 l milk 100 MJ^{-1}, the average was 21.6 l milk 100 MJ^{-1}. In 2000–2001, 90% of the dairy farms operated at 16.7–39.0 l milk 100 MJ^{-1}, with an average of 27.1 l milk 100 MJ^{-1}. This corresponds with an increase in energy productivity of 25% between 1989 and 2001. Considering the decreased total energy use (Table 4), the studied dairy farms succeeded in keeping up or increasing their milk production with a significantly lower energy use, mainly originating from a lower use of mineral fertilisers and concentrates. Aspects of operational management that are potentially effective for decreasing the use of mineral fertilisers and concentrates might be found in measures such as crop rotation and ley/arable rotation, ration optimization and increased forage milk production, incorporation of clover-based swards or improved manure management and manure quality (Nevens et al., 2006). The actual management measures leading to the observed increased production efficiency could not be derived from the FADN data.

The observed energy productivities in our study are consistent with values from literature: 15.4 l milk 100 MJ^{-1} (Hageman and Mandersloot, 1994), 13 to 26 l milk 100 MJ^{-1} (Hageman, 1994), 23 to 32 l milk 100 MJ^{-1} (Halberg, 1999) and 30 l milk 100 MJ^{-1} (Koskamp et al., 2000).

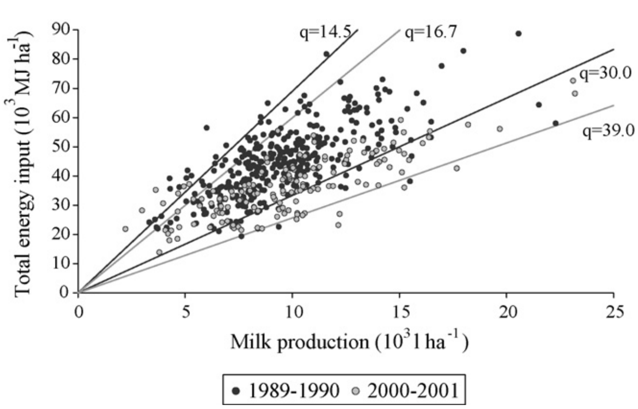

Fig. 1. Energy input in relation to produced milk: data of Flemish specialised dairy farms in 1989–1990 and 2000–2001. Lines are isoquants of energy productivity: q = energy productivity (l milk 100 MJ^{-1}).

Table 5
Average characteristics of the specialised dairy farms in the FADN and of a subgroup of 24 top performing farms with regard to energy productivity (data of 1989, 1990, 2000 and 2001)

Topic	Top performing farms ($n = 24$)	All farms ($n = 483$)	Top performing farms compared to all	
			Absolute	Relative (%)
Utilised area (ha)	28.9	29.1	−0.2	99.3
Stocking rate (cows ha^{-1})	1.9	1.7	0.23	113.5
Share of dairy cows (%)	64.9	51.3	13.6	126.5
Energy input (MJ ha^{-1})				
Diesel	6489	7612	−1123	85.2
Lubricants	399	527	−128	75.7
Electricity	3605	4074	−469	88.5
Other sources	53	137	−84	38.7
Mineral fertiliser	7896	12659	−4763	62.4
Seeds	135	164	−29	82.3
Pesticides	189	199	−10	95.0
Machines	1965	2288	−323	85.9
Concentrates	9955	14484	−4529	68.7
Forages	496	259	237	191.5
Total	31182	42402	−11220	73.5
Milk production				
l ha^{-1}	12104	9669	2435	125.2
l cow^{-1}	5986	5521	465	108.4
Energy productivity (l 100 MJ^{-1})	38.8	22.8	16	170.2
N use efficiency (l kg^{-1} N surplus)	48.9	30.7	18.2	159.3
Gross value added (€ 100 l^{-1})	26.35	22.28	4.07	118.3

Table 5 shows that the total energy input of a group of 24 best performing dairy farms (the 5% most energy efficient farms from our dataset) was only 73.5% of the average energy input of the total dairy farm set. The lower energy input on these farms originated mainly from a lower use of mineral fertilisers (−38%) and concentrates (−31%). The lower input of mineral fertilisers can not be attributed to preferential weather conditions or inherent soil fertility (influencing crop and forage yields), since the group of 24 best performing farms, as well as the group of worst performing farms (with lowest energy efficiency – not mentioned in Table 5) both contained farm data from all years (1989, 1990, 2000 and 2001) and from all agricultural regions in Flanders. The lower input of concentrates could be attributed to the fact that the top performers 'outsource' a less energy efficient part of the production (breeding heifers), as can be seen from Table 5 (share of dairy cows is 26% higher on the top performing farms).

Despite the lower use of inputs, milk production per ha was 25% higher on the best performing group, compared to the average for all dairy farms. This was achieved by a higher milk production per cow (+8%) and a higher stocking rate (+14%). This shows that the most energy efficient farms were not necessarily the most extensive ones, on the contrary, they were characterised by highly productive cows and a high stocking rate.

The trendsetting farms showed an average gross value added per litre milk that was 18% higher and a N use efficiency that was even 59% higher compared to the average of the total dairy farm set (Table 5). The N use efficiency was hereby defined as the ratio between the farm's product outputs (litres of produced milk) and the farm-gate N surplus (=N input − N output) (Meul et al., 2005).

Those results show that energy efficiency on farms can be optimised through management practices. Hereby, an energy efficient management has positive trade-offs on the N use efficiency and can be combined with good economic results. The latter was also found for N use efficiency on specialised dairy farms in Flanders (Nevens et al., 2006).

Based on the energy productivity results of the best performing dairy farms, a target value of 35 l milk 100 MJ^{-1} can be realised in practice, at production levels of 12,000 l ha^{-1} or higher.

3.2.2. Pig farms

Fig. 2 shows the relationship between total energy input on farm level and the weight of produced piglets (for sow herds) or the weight of produced pig carcasses (for fattening herds). The specialised sow herds showed an average energy productivity of 2.8 kg piglets 100 MJ^{-1}. The specialised fattening herds had an average energy productivity of 6.0 kg carcass 100 MJ^{-1}, comparable with values of 5–10 kg 100 MJ^{-1} found by Halberg (1999) on Danish pig farms. Our results show that piglet production should not be compared to the production of fattening pigs, since the latter is more energy efficient (of course piglets are necessary to establish fattening herds).

Since the FADN only contained information on 21 sow herds, we could not make a sound statistical analysis of the

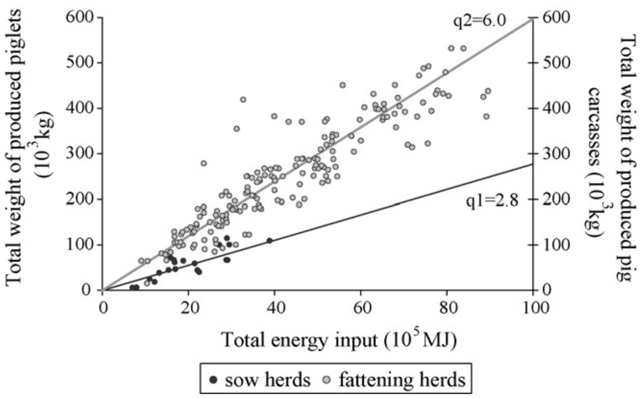

Fig. 2. Energy input in relation to produced outputs: data of Flemish specialised pig farms in 1997–1998. Lines are isoquants of energy productivity: $q1$ = energy productivity of sow herds (kg piglets 100 MJ^{-1}); $q2$ = energy productivity of fattening herds (kg carcass 100 MJ^{-1}).

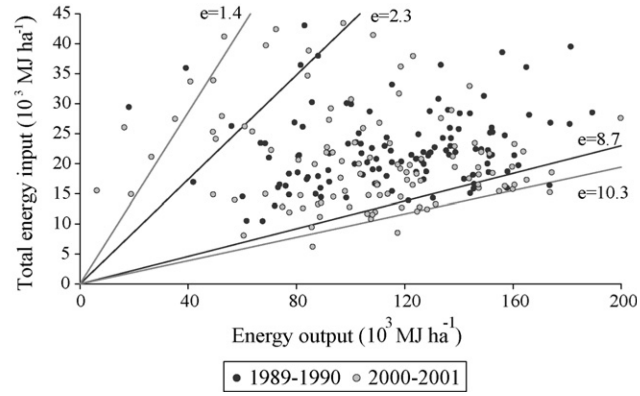

Fig. 3. Energy output in relation to energy input on Flemish specialised arable farms in 1989–1990 and 2000–2001. Lines are isoquants of energy balance: e = energy balance (energy output/input; no units).

farm characteristics to explain the variations in energy productivity. For the fattening herds, we compared the characteristics of the 5% most energy efficient farms with the average characteristics of all fattening herds (Table 6). The average total energy input per FPE on the top performing farms was 29% lower than the average. Mainly diesel (−47%) and feed use (−25%) were significantly lower. On the other hand, the total weight of produced carcass per FPE was 16% higher on the top performing group, which resulted in a 63% higher energy productivity. The gross value added per kg carcass on the top 5% of the farms was comparable to the average of all fattening pig farms.

Based on the results of the best performing fattening pig farms, a production of 7.5 kg carcass 100 MJ^{-1} is an achievable target value for pig farms specialised in the production of fattening pigs.

3.2.3. Arable farms

Fig. 3 shows the large variation in the energy balances of the specialised arable farms. In 1989–1990, the average energy balance was 5.5 and 90% of the farms obtained an energy output between 2.3 and 8.7 MJ MJ^{-1} of energy input. In 2000–2001, 90% of the farms operated between energy balance isoquants of 1.4 and 10.3, with an average of 5.9. Contrary to the dairy farms, there was no clear shift in energy use efficiency from 1989–1990 to 2000–2001. A change in the applied crop rotations and the relatively low decrease in applied mineral fertiliser (Table 4) could explain this difference. On arable farms, there is less need to reduce the amount of mineral fertilisers, since they have less trouble to be manure legislation compliant.

Depending on the crop rotation, production method and fertilisation rate, energy balances between 0.7 and 16.2 were

Table 6
Average characteristics of the specialised fattening pig farms in the FADN and of a subgroup of 9 top performing farms with regard to energy productivity (data of 1997 and 1998)

Topic	Top performing farms (n = 9)	All farms (n = 174)	Top performing farms compared to all	
			Absolute	Relative (%)
Number of pigs (FPE[a])	1700	1332	368	127.6
Energy input (MJ FPE^{-1})				
Diesel	401	750	−348	53.5
Lubricants	3	6	−4	43.3
Electricity	177	190	−13	93.0
Other sources	6	12	−7	44.5
Mineral fertiliser	68	50	18	135.3
Seeds	2	5	−3	33.4
Pesticides	5	8	−3	62.0
Machines	11	23	−12	46.1
Feed	1797	2411	−613	74.6
Total	2470	3457	−987	71.4
Weight of produced carcass (kg FPE^{-1})	232	200	32	116.3
Energy productivity (kg 100 MJ^{-1})	9.4	5.8	3.6	162.7
Gross value added (€ kg^{-1})	0.31	0.32	−0.01	96.9

[a] Fattening pig equivalent.

Table 7
Average characteristics of the specialised arable farms in the FADN and of a subgroup of 12 top performing farms with regard to energy balance (data of 1989, 1990, 2000 and 2001)

Topic	Top performing farms (n = 120)	All farms (n = 229)	Top performing farms compared to all	
			Absolute	Relative (%)
Cultivated area (ha)	39.0	56.7	−17.7	68.8
Cereals in rotation (%)	47.4	34.0	13.4	139.4
Energy input (MJ ha^{-1})				
Diesel	4271	7923	−3652	53.9
Lubricants	226	539	−313	41.9
Electricity	352	1073	−721	32.8
Other sources	181	424	−243	42.7
Mineral fertiliser	5910	8179	−2269	72.3
Seeds	373	474	−101	78.7
Pesticides	706	1239	−533	57.0
Machines	895	1949	−1054	45.9
Total	12914	21800	−8886	59.2
Energy output (MJ ha^{-1})	136694	112397	24297	121.6
Energy balance	10.6	5.2	5.4	205.3
Gross value added (€ ha^{-1})	1061	1160	−99	91.5

reported in other studies concerning energy use efficiency on arable farms (Hülsbergen et al., 2001; Helander and Delin, 2004; Ozkan et al., 2004).

Table 7 shows that the average energy input of a group of 12 top performing arable farms was only 60% of the average energy input of all arable farms, owing to a lower diesel use (−46%) and a lower use of mineral fertilisers (−28%); while the energy output was 22% higher. The result was an energy balance twice as high as the average energy balance of all arable farms. The high energy use efficiency of the best farms was highly determined by their crop rotations: the average share of cereals (mainly winter wheat) was almost 40% higher. As shown in Table 8, cereal crops and sugar beet combine a high energy output per ha with a low energy demand and therefore have a high energy balance. Farms with a large share of cereals and sugar beet in their crop rotation can thus be expected to have a higher energy balance.

This aspect also explains why the average gross value added of the trendsetting farms was lower than the average of all farms (−8%, Table 7): in Flanders, cereals generally have the lowest price of all arable crops, the most lucrative crops being vegetables.

Since the energy balance is highly influenced by the grown crops in the rotation, specific target values should be set for each separate crop on arable farms, but the FADN data are not enough detailed to apply this method.

3.3. Discussion: how to guide farms towards a higher sustainability level?

For the dairy and pig farms, we extracted a group of best performers (5% of the total set) that showed the highest energy use efficiency. A detailed description of the characteristics and operational management aspects of those top performing farms could allow an identification of the specific farm aspects underlying their remarkably good energy efficiency performances. Those farms could then be set as an example for others and be used in education and extension projects. Examples of such ‘learning networks’ can be found in a number of Dutch projects: ‘De Marke’ (Anonymous, 2003), ‘AP-Minderhoudhoeve’ (Overvest, 2002), ‘Koeien en Kansen’ (Oenema, 2003; De Vries, 2003), ‘Bioveem’ (Snijders and Everts, 2000) and ‘Vel & Vanla’ (Van der Hem, 2003).

Besides that, an indicator-based farm evaluation system can be a helpful instrument to guide farms towards a higher level of sustainability. Several systems focussing on ecological sustainability are in use: Wetterich and Haas (1999) in Germany, Van Zeijts et al. (1999) in The Netherlands and Lewis and Bardon (1998) in the UK. More holistic systems also include indicators for social en economic sustainability: Rigby et al. (2001) in the UK and Vilain (2000) in France. Depending on the system, indicator benchmarks are based on average values, comparable farms, top performers or pre-defined optima.

Table 8
Energy balance (output/input) for the production of major arable crops (according to Hülsbergen et al., 2001)

	Potato	Winter wheat	Winter barley	Spring barley	Sugar beet
Energy input (MJ ha^{-1})	24430	19330	17180	14660	29700
Energy output (MJ ha^{-1})	105100	278800	161300	144600	330100
Energy balance	4.3	14.4	9.4	9.9	11.1

In Flanders, a prototype of an indicator-based farm evaluation system is currently being developed (Mulier et al., 2004), taking into account ecological, economic and social aspects of sustainability. This system allows farmers to position their farm in terms of sustainability and to assess the effects of a specific measure on the relevant economic, ecological and social aspects of their business (trade-off effects).

4. Conclusions

We calculated total energy use on a representative set of Flemish specialised dairy, arable and pig farms and we studied the changes in energy use and energy use efficiency on farm level between 1989 and 2001. The results showed that indirect energy use, particularly the use of mineral fertilisers and animal feed, accounted for a high share of the total energy use on the farms. Diesel use took the major part of direct energy use. Therefore, decreasing the energy use on farms should not only be tackled by a lower diesel use, but also by lower uses of farm inputs like mineral fertilisers and concentrates.

We calculated energy productivity on dairy and pig farms as a measure of energy use efficiency. For both farm types, the most energy efficient farms were intensive farms, which combined a high production with a low energy use. Compared to the average of all farms, the most energy efficient farms had a comparable or even higher gross value added per unit of production. This illustrates that an energy efficient management can go hand in hand with a good economic situation.

Based on the energy productivity values of the top 5% farms, we proposed target values of 35 l milk 100 MJ^{-1} and 7.5 kg carcass 100 MJ^{-1} for energy use on Flemish dairy and pig fattening farms, respectively. On arable farms, the energy balance (as a measure of energy use efficiency) was highly dependent on the crop rotation. For that reason, we recommend to calculate energy balances on field level for each separate crop, instead of on farm level. However, to achieve this, a lot of detailed information on the used amounts of inputs for each separate crop will be necessary.

Acknowledgements

The authors gratefully thank the Centre for Agricultural Economics (D. Van Lierde and L. Lauwers) for kindly putting the FADN data at their disposal.

References

Anonymous, 2003. Resultaten proefbedrijf ‘De Marke’. Accessed on: http://www.koeienenkansen.nl.

Australian Institute of Energy, 2004. Accessed on: http://www.aie.org.au.

Bonnez, 2006. Iscal Sugar nv., personal communication.

Boustead, I., 2003. Eco-profiles of the European Plastics Industry, Olefins. Association of Plastics Manufacturers (APME), Brussels.

Commission of the European Communities, 1985. Commission decision of 7 June 1985 establishing a Community typology for agricultural holdings (85/377/EEC). Office for Official Publications of the European Communities, Luxemburg.

Corré, W., Schröder, J., Verhagen, J., 2003. Energy use in conventional and organic farming systems. In: Proceedings No. 511, International Fertiliser Society, New York.

Dalgaard, T., Halberg, N., Porter, J.R., 2001. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. Agric. Ecosyst. Environ. 87, 51–65.

de Haan, M.H.A., Feikema, W., 2001. Energiegebruik lagekostenbedrijf. Research Institute for Animal Husbandry, Animal Sciences Group, Wageningen.

de Jonge, A.M., 2004. Eco-efficiency improvement of a crop protection product: the perspective of the crop protection industry. Crop Prot. 23, 1177–1186.

De Vries, C., 2003. Duurzaam pionieren. In: Presentatie ‘Koeien & Kansen’—workshop: ‘Stikstofhuishouding & milieukwaliteit’, Wageningen, April 22.

Dekkers, W.A., 2002. Kwantitatieve Informatie, akkerbouw en vollegrondsgroenteteelt 2002. PPO Research Unit for Arable Farming, Multifunctional Agriculture and Field Production of Vegetables, Wageningen.

Environmental Management for Agriculture (EMA), 2002. A Self Audit, Evaluation and Reporting Package for Farmers and Growers covering all Aspects of Environmental Management. University of Hertfordshire, Hatfield.

FPS Economy, SMEs, Self-employed and Energy, 2004. Accessed on: http://mineco.fgov.be.

Gezer, I., Acaroğlu, M., Haciseferoğullari, H., 2003. Use of energy and labour in apricot agriculture in Turkey. Biomass Bioenergy 24, 215–219.

Gliessman, S., 2000. Agroecology, Ecological Processes in Sustainable Agriculture. CRC Press LLC, Boca Raton.

Hageman, I.W., 1994. Invloed bedrijfsfactoren op energiegebruik melkveebedrijven. Research Institute for Animal Husbandry, Animal Sciences Group, Wageningen.

Hageman, I., Mandersloot, F., 1994. Model energieverbruik melkveebedrijf. Research Institute for Animal Husbandry, Animal Sciences Group, Wageningen.

Halberg, N., 1999. Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. Agric. Ecosyst. Environ. 76, 17–30.

Helander, C.A., Delin, K., 2004. Evaluation of farming systems according to valuation indices developed within a European network on integrated and ecological arable farming systems. Eur. J. Agron. 21, 53–67.

Hülsbergen, K.-J., Feil, B., Biermann, S., Rathke, G.-W., Kalk, W.-D., Diepenbrock, W., 2001. A method of energy balancing in crop production and its application in a long-term fertilizer trial. Agric. Ecosyst. Environ. 86, 303–321.

Jollands, N., Lermit, J., Patterson, M., 2004. Aggregate eco-efficiency indices for New Zealand—a principal components analysis. J. Environ. Manage. 73, 293–305.

Jones, M.R., 1989. Analysis of the use of energy in agriculture—approaches and problems. Agric. Syst. 29, 339–355.

Koskamp, G.J., van der Laan, O.J.H., Middelkoop, N., van der Schans, F.C., 2000. Energie op de Marke. Centre for Agriculture and Environment, Utrecht.

Lewis, K.A., Bardon, K.S., 1998. A computer-based informal environmental management system for agriculture. Environ. Model. Softw. 13, 123–137.

Maertens, A., Van Lierde, D., 2003. Het energieverbruik in de Vlaamse land-en tuinbouw. Ministry of the Flemish Community, Administration of Agriculture and Horticulture, Brussels.

Meul, M., Nevens, F., Verbruggen, I., Reheul, D., Hofman, G., 2005. Eco-efficiency of specialised dairy farms in Flanders. In: Proceedings of the 11th Annual International Sustainable Development Research Conference, Helsinki, June 6–8.

Ministry of Agriculture, 2001. De Belgische landbouwteelten: een overzicht. Ministry of Agriculture, Brussels.

Moerschner, J., Lücke, W., 2002. Energy investigations of different intensive rape seed rotations—a German case study. In: van Ierland, E.C., Oude Lansink, A. (Eds.), Economics of Sustainable Energy in Agriculture. Kluwer Academic Publishers, Dordrecht, pp. 27–40.

Mulier, A., Nevens, F., Reheul, D., Mathijs, E., 2004. Ontwikkeling van een beoordelingssysteem voor de duurzaamheid van de Vlaamse land-en tuinbouw op bedrijfsniveau. Steunpunt Duurzame Landbouw, Gontrode.

Nevens, F., Verbruggen, I., Reheul, D., Hofman, G., 2006. Farm gate nitrogen surpluses and nitrogen use efficiency of specialized dairy farms in Flanders: evolution and future goals. Agric. Syst. 88, 142–155.

NOVEM, 1992. De haalbaarheid van de produktie van biomassa voor de Nederlandse energiehuishouding: eindrapport. The Netherlands Agency for Energy and the Environment, Apeldoorn.

Oenema, J., 2003. Stikstofhuishouding in 'Koeien & Kansen'. In: Presentatie 'Koeien & Kansen'-workshop: 'Stikstofhuishouding & milieukwaliteit', Wageningen, April 22.

Overvest, J., 2002. Voorstelling resultaten AP Minderhoudhoeve. In: PMOV-studiedag, Swifterbant, The Netherlands, juni 20.

Ozkan, B., Akcaoz, H., Fert, C., 2004. Energy input-output analysis in Turkish agriculture. Renew. Energy 29, 39–51.

PCA, 2006. Interprovinciaal Proefcentrum voor de Aardappelteelt, personal communication.

Pervanchon, F., Bockstaller, C., Girardin, P., 2002. Assessment of energy use in arable farming systems by means of an agro-ecological indicator: the energy indicator. Agric. Syst. 72, 149–172.

Pimentel, D., Hurd, L.E., Belloti, A.C., Forster, M.J., Oka, I.N., Scholes, O.D., Salway, A.G., 1996. UK Greenhouse Gas Emission Inventory 1990–1994. AEA Technology and Department of the Environment. AEA/20092001/Issue 1.

Refsgaard, K., Halberg, N., Kristensen, E.S., 1998. Energy utilization in crop and dairy production in organic and conventional livestock production systems. Agric. Syst. 57, 599–630.

Rigby, D., Woodhouse, P., Young, T., Burton, M., 2001. Constructing a farm level indicator of sustainable agricultural practice. Ecol. Econ. 39, 463–478.

Snijders, P., Everts, H., 2000. Mineralenbalans, stikstofbinding en waterkwaliteit. In: Biologische veehouderij en management (Bioveem), Publicatie 144, Praktijkonderzoek Rundvee, Schapen en Paarden, Lelystad, The Netherlands, pp. 61–64.

USDA, 2004. USDA National Nutrient Database for Standard Reference. United States Department of Agriculture. Accessd on: http://www.nal.usda.gov/fnic/foodcomp/search.

Van der Hem, A., 2003. De cijfers achter Vel & Vanla. Natuurlijk in balans 4, 7–9.

van der Werf, H.M.G., Petit, J., Sanders, J., 2005. The environmental impacts of the production of concentrated feed: the case of pig feed in Bretagne. Agric. Syst. 83, 153–177.

Van Zeijts, H., Kool, A., Rougoor, C.W., van der Schans, F.C., 1999. Systemen om de duurzaamheid van veebedrijven te waarderen. CLM-rapport 431-1999.

Vilain, L., 2000. La méthode IDEA: Indicateurs de durabilité des exploitations agricoles. Guide d'utilisation. Educagri editions, Dijon.

Vito, 2004. EMIS, het energie en milieu informatiesysteem voor het Vlaamse Gewest. Flemish Institute for Technological Research, Mol. Accessed on: http://www.emis.vito.be.

WBCSD, 2000. Eco-efficiency. Creating more Value with Less Impact. World Business Council for Sustainable Development, North Yorkshire. Accessed on: http://www.wbcsd.org.

Wells, D., 2001. Total energy indicators of agricultural sustainability: dairy farming case study. Technical Paper 2001/3. Ministry of Agriculture and Forestry, Wellington. Accessed on: http://www.maf.govt.nz.

Wetterich, F., Haas, G., 1999. Őkobilanz Allgäuer Grünlandbetriebe. Intensiv-Extensiviert-Őkologisch. Schriftenreihe Institut für Organischen Landbau, August 1999.